PROPERTY OF
THE LIBRARY
6 DEC 1962
USAF

OAR:
The Basic Research Agency
of The United States Air Force

F OFFICE OF SCIENTIFIC RESEARCH / A F CAMBRIDGE RESEARCH LABORATORIES / AERONAUTICAL RESEARCH LABORATORIES / EUROPEAN OFFICE O A R

NO. 19 3 DECEMBER 1962

WHAT CAN MAN DO IN MAN-MACHINE SYSTEMS?

Dr. H. T. Sander, Behavioral Sciences Division, AFOSR

Man the tool maker has been building machines for centuries which can do his work *for* him, but now man is building complex electronic machines that do his work *with* him. Instead of just using a machine, man must now cooperate with it. To understand a man-machine system it is necessary to know what each component can do. We generally know much more about the capabilities of the machine than we do about man's capabilities in a man-machine system.

If we take a total view of a man-machine system, some important questions have to be answered: What is the body's organization for action? How does man communicate with the machine and what kind of information does he need to perform his role in the system? What is the measure of man's ability to use signs, symbols and information codes to communicate with machines? What functions can be performed more efficiently by men than by machines? How can man-machine systems be designed so that man's job is more interesting and challenging?

Dr. Paul M. Fitts, Professor of Psychology at the University of Michigan has been concerned with answering these questions since he first became engaged in psychological research for the Air Force during World War II.

Since 1958 Professor Fitts has been directing a basic research project on information handling and decision making by individuals and small teams, sponsored by the Air Force Office of Scientific Research. This research program is aimed at developing general principles and theory for the prediction of levels of performance of individuals, teams and man-machine systems in handling information. The program studies the level of performance as a function of task and system characteristics such as the kinds of information processing required, the way a group is organized, and the kind of input and feedback information displayed to individuals or shared by a team.

One of the first phases completed in the current research program was the development of a workable classification, or taxonomy, of information processing tasks. The five kinds of information processing in Professor Fitts' taxonomy are: complete-information processing, partial-information transmission, information reduction, heuristic problem solving, and decision making.

Complete-information processing is the simplest form. It involves transposing from one

form of communication to another, such as typing stenographic notes, playing music, translating a foreign language, or reading aloud. In such activities all information in the stimulus sequence reappears in the response sequence. This type of information processing places minimal judgmental or decision-making demands on the human operator. A typical research problem at this level involves the study of rates of information transmission as a function of the size of the coding alphabet. Computers and people differ considerably with regard to the size of the code (alphabet) they use most efficiently.

In *partial-information* transmission tasks man is asked to apply simple selection or filtering rules. Here he relys on normal human perceptual and mental characteristics, such as the tendency to classify, select, organize or otherwise reduce incoming information. Man is never able to deal directly with all of the information in his environment and filters the information he wants. The radar monitor, the proofreader and the inspector respond only to events that belong to a highly restricted class of stimuli and disregard all others. Research on partial-information transmission tasks seeks ways of coding information to make it easier to find a target in a photograph, to check-read an instrument panel, or to locate a particular reference in a card file.

Information reduction is a type of information processing in which the person responds to all of a given body of stimuli yet summarizes, condenses, or reduces the information. In this kind of task it is not possible to recover all of the stimulus information if only the response is known. Writing an abstract of a scientific project such as this, or performing an additional task in which only successive sums are reported are examples of information-reduction. In a doctoral dissertation done in connection with Professor Fitts' project, Dr. Michael Posner found that the time required for the thought process involved in mental arithmetic can be predicted on the basis of the amount of information reduction required.

A more complex type of information processing is *problem solving* in which either an algorithmic or a heuristic method, or both, may be used in dealing with available information. An algorithmic method is a prescribed series of steps which, when correctly applied, assures an optimal or perfect solution. An algorithm is used, for instance, to extract a square root. The two necessary conditions for the application of an algorithm are that an algorithm is known and that it is feasible to apply it in the given solution. If one of these conditions is not met, then heuristic procedures have to be used. "Heuristic" means using the information obtained in one step of a solution to aid in deciding upon the next step, and also using a problem-solving procedure that does not guarantee an optimal solution.

Certain problems such as personnel assignment, production and transportation scheduling, are amenable to heuristic solution. Human procedures for solving this class of problems are especially interesting to psychologists because people make successive choices. Although people are relatively good at solving this kind of problem, the procedures they use are not yet well understood. Research on heuristic problem solving involves the study of sequences of steps employed in the solution, the effectiveness of different over-all strategies, and the influence of different ways of coding the information needed to attack the problem.

The most difficult kind of information-processing task in Fitts' taxonomy is *decision making*, which may be defined as the selection of a course of action on the basis of incomplete information, or in the face of risk. There are differential values, or payoffs, associated with the different possible outcomes. Hence, decision theory was first employed in studies of betting behavior. Recently, Professor Fitts has applied this theory to the prediction of the time required to discriminate among signals and make choices when different signals vary greatly in probability of occurrence.

These five types of information processing tasks may be affected by certain conditions in the situations in which they operate. Feedback, or knowledge of results, is one of the more important of these. It may take many forms, from absence of any information about the effects of actions, to complete information. It may also be delayed or provide only partial information. In recent experiments it was found that college students would work harder for immediate information on achievement, that is, feedback given by pinball lights, than they would for a modest monetary bonus.

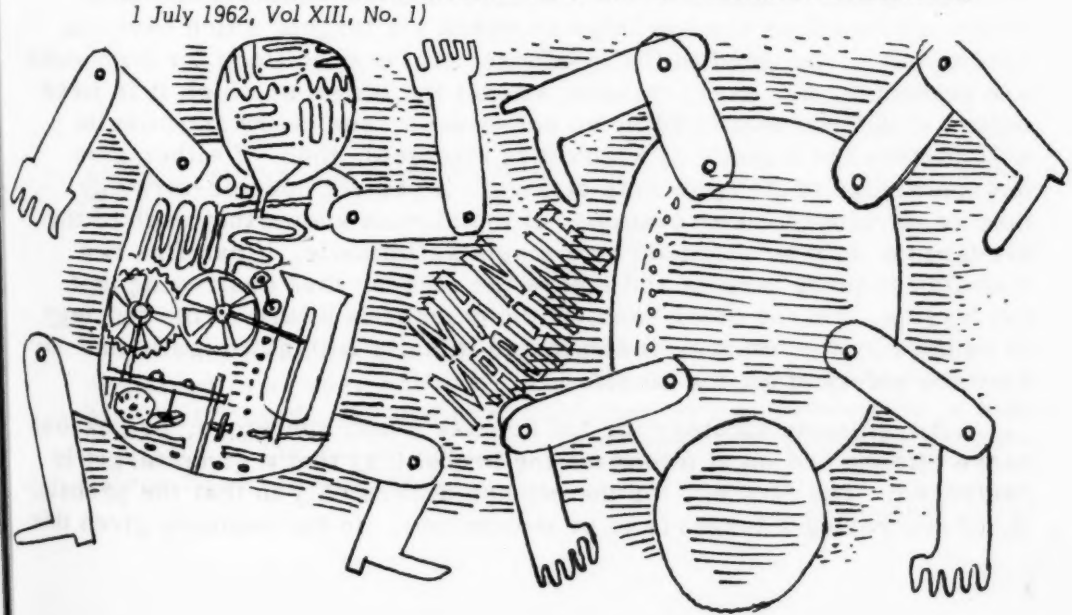
In tasks done by teams instead of individuals, a condition that affects information-processing tasks is the degree to which information and responsibility are shared. A related independent variable is the degree of interaction (including communication) permitted by the arrangement of men and machines in the system. In his research, Professor Fitts has given special attention to the spontaneous development of team relationships in a complex task combining several information processing activities.

A dynamic version of a heuristic problem-solving task was studied in a special experiment by Dr. Heber G. Moore, one of Fitts' assistants. This experimental task simulated the dispatching, bookkeeping, monitoring, and decision-making functions of a taxi control system. The primary task of one of the subjects was to assign cabs to pick up passengers so that elapsed time and distance traveled by the cab were minimized. Subject number two had to monitor the positions of the cabs, start them on their runs, and keep the records. Twelve two-man teams were run through the experiment under various conditions of input load and access to feedback information.

The results of these experiments revealed important effects on team performance of load and accessibility to information. Teams working under high-load conditions performed, in general, better than teams under low-load conditions. This finding was in agreement with earlier studies which indicated that under high-load conditions teams did not become complacent but instead tried harder to improve. It had also been hypothesized, that if the load were very high, the team performance would break down. This did not occur, however, within the limits of the loads studied. The effect of free access to information was over-all improvement of performance, especially when the load was high. Free access to information allowed a certain flexibility in the different information-processing jobs done by each team member. Because one man could pick up the slack, relieving his busier partner, the team's performance improved.

The general thesis, that a great variety of everyday human activities can be viewed as information-processing tasks, appears to be borne out by these laboratory results. It has been found that human efficiency varies greatly from one task to another, depending on the information codes used, the amount of information available, and the degree of information sharing between men and machines. These findings are helping to answer the important question: What can man do in man-machine systems?

(Condensed paraphrase of an article in the University of Michigan Research News, 1 July 1962, Vol XIII, No. 1)



OPTIMUM STRATEGIES

Dr. WILLIAM R. McEWEN, Consultant, Directorate of Research Analyses (AFOSR)

The attack and defense of targets with missiles leads to interesting problems on probability to which both game theory and classical probability can be applied. As a simple example consider the case where six missiles are available to attack six targets which have six antimissiles assigned to their defense. If the conditions for both sides are perfect (i. e., every missile will hit the target at which it is fired unless it is first destroyed by an antimissile, and every antimissile will destroy the missile at which it is directed), then, if either side has knowledge of its opponents strategy, a perfect counter-strategy may be developed. For example, if the offense knows that each of the six targets is to be defended by a single antimissile, it can fire two missiles at three targets and ignore the others, thus destroying half the targets. On the other hand, if the defense is aware of the strategy to be used by the offense, it can match missile with antimissile and insure the safety of all the targets.

An optimum strategy for the defense must, therefore, be unknown to the offense and must minimize the probability that a given target is destroyed. The strategy for the offense differs only in that the probability of destroying a target is to be maximized. In the example given this

can be accomplished by assigning to each target either zero, one, or two weapons, the particular number to be determined by chance in a manner which will use all six weapons. It can be shown by the methods of classical probability and of game theory that if the offense adopts such a strategy, the probability that a particular target is destroyed is at least one third against any and all defensive strategies. Its adoption by the defense will insure that this probability is at most one third.

The preceding results hold for any number of targets, say t, if there is an average of one missile and one antimissile per target. In the general case where we have an average of n missiles and m antimissiles per target, the offense should attack each target with either

$$k, \text{ or } (k+1), \text{ or } \ldots, \text{ or } (2n-k) \text{ missiles}$$

and the defense defend with either

$$\ell, \text{ or } (\ell+1), \text{ or } \ldots, (2m-\ell) \text{ missiles}$$

where $k = \ell = 0$ if $m = n$

$k = 0, \ell = m - n$ or $m - n - 1$ if $m > n$

and $\ell = 0, k = n - m$ or $n - m - 1$ if $m < n$.

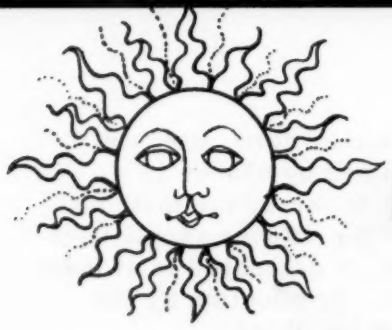
If $m \geq n$ the probability that any specified target is destroyed is

$$\frac{n}{2m+1}$$

while if $m < n$ the probability is

$$\frac{2n-m}{2n+1}$$

These results and others, together with their derivations, are contained in a paper entitled "The Attack and Defense of Targets by Missiles" by W. R. McEwen, published by the Directorate of Research Analyses of the Air Force Office of Scientific Research at Holloman Air Force Base, New Mexico.



ELECTRONS *from the SUN*

RAY R. HEER, Jr.
Nuclear Physics Division (AFOSR)

One of the pleasant things in life is to call attention to a First; this one concerns the detection of high energy electrons from the sun. In a previous report (28 July 1961) the detection of primary electrons was pointed out. But at the time it wasn't possible to delineate the source. Now it is.

Drs. Peter Meyer and Rochus Vogt, with AFOSR support, have made another series of balloon flights with their cosmic ray detector which consists of multiple layers of lead absorber and scintillation counter - thus providing for energy discrimination - surrounded by scintillators in anti-coincidence. The flights took place in July and August 1961. One flight was on 22 July during the solar disturbed conditions caused by the Class 3^+ solar flares of 18 July and 20 July. A Class 3 flare is one that covers approximately 5/1000 the visible surface of the sun; the $^+$ is a measure of brightness. The two other flights were made on 1 August and 8 August, both being after quiet solar periods. On a plot of flux vs altitude the curves for excited and quiet periods are the same, within experimental error, up to about 100,000 feet. At this point the two curves diverge abruptly until at about 119,000 feet the excited day electron flux is approximately 2.6 times the quiet day electron flux.

Since there is this quiet day flux it is evident that the sun is not the only electron source. If we subtract the 1 August flux from the 22 July flux the remainder should represent the solar electron flux. Doing this one finds there are some 368 ± 50 electrons/m^2 sec steradian in the energy range 100Mev E 130Mev which may be attributed to the sun. The solar differential spectrum in this range fits well a power low with E^{-2}, which is quite like the exponent for other cosmic ray components in this range.

As far as it is known, this is the first direct detection of solar electrons. Further detection and study of such events will add to our knowledge of solar phenomena and of the conditions, especially as concerns magnetic fields and plasma, which prevail along a sun-earth line following this type solar emission. And - as has been pointed out so many times before - such knowledge may be important in such fields as communication, navigation and even survival in space.

a VIBRATING dilemma

EDMUND P. GAINES, Jr.,
Major, USAF
General Physics Division
AFOSR

Ever since man has been capable of creative thought, he has, in one way or another, been concerned with the related problems of distortions and vibrations in solids. In fact, his very survival has often depended upon this knowledge, for it has enabled him, over the years, to design a variety of structures, tools, and weapons essential for his continued existence. For his enjoyment, such knowledge has also provided him the means to design many types of musical instruments which use vibrating materials as the source of sound.

Curiously, however, it did not occur to anyone until just 300 years ago that here was a problem worthy of serious scientific study. In 1638, Galileo first formulated the problem of relating the force to deflection in flexible beams and emphasized the importance of a solution. Until that time, the design of buildings, bridges, bows, and other things using beams and rods to support loads was accomplished by trial and error, often with dramatic and sometimes fatal results. Although Galileo stated the problem, it remained for Hooke to discover a mathematical basis for a solution. In 1676, he published his results and stated the natural law of proportionality between force and extension (or compression) now known as Hooke's Law. Later, in 1821, the French mathematician Navier established the general differential equations expressing the conditions for equilibrium and vibration of elastic solids. The Navier equations together with Hooke's Law form the foundation of modern mathematical theory of elasticity.

In the years since Navier published his generalized equations, there have been many attempts to apply them to practical problems. All useful solutions, however, have been obtained by making certain (and often appropriate) approximations. This has been necessary even

for very simple geometries such as a cylinder. In this case, with bending along the axis of rotation for example, the solution requires that the diameter be assumed negligible in comparison with the length. To date, all attempts to give an exact solution without such approximations have failed, the reason being primarily a mathematical one involving the requirement to satisfy simultaneously certain conditions at the boundaries of the body. The result is that if one wants to know exactly at what frequencies a body can be made to vibrate, it is necessary to actually build the object and test it. Often the accuracy required in determining the natural frequencies of vibration is sufficiently small that the approximate mathematical solutions will suffice. As often, however, these frequencies must be known much more accurately. Think how much time, money, and effort would be saved if this phase of testing could be omitted safely. Although at present this is admittedly an overly optimistic thought, nevertheless, it underlies the reason why AFOSR recently undertook sponsorship of a theoretical study on vibration theory directed by Dr. D. S. Moseley.

Dr. Moseley, who is presently with Vitro Laboratories, Silver Spring, Maryland, is concentrating on the study of elastic vibrations in solid cylinders of arbitrary dimensions. He hopes to obtain an exact solution to the problem by a novel choice of certain mathematical relationships which describe the dilatation and shear waves within the body.

Dr. Moseley, of course, is not the first to address himself to this problem. Others, notably Pochhammer, Chree, and Lord Rayleigh during the late 19th Century and, recently, T. R. Kane and R. D. Mindlin, have all successfully treated special cases of the vibrating cylinder. These special cases, however, limited the dimensions to certain ranges. For example, the solution given by Kane and Mindlin limited the range of the length-to-diameter ratios for disc-like cylinders to between 0.12 and 0.4. Even so, this restriction permitted only calculation of frequencies for the fundamental and first overtone. Because of the approximations used, their relation is unable to predict overtones higher than the first. Dr. Moseley, however, recently discovered a new way of obtaining solutions to the equations of motion for a cylinder with stress - free surfaces. His method has suggested an entire set of solutions that have not been tried before. The general mathematical description of the motion that Dr. Moseley has been able to formulate is now being altered so as to involve more simple mathematical terms. The next step is to include the mathematical conditions expressing the physical situation at the geometrical boundaries of an actual cylinder. When this has been done, an exact solution will have been found and dilemma that has been vibrating physicists for many years will be resolved.

Terrestrial Sciences Laboratory (AFCRL)

The geodetic satellite ANNA was successfully launched on 31 October 1962. The satellite will provide AFCRL scientists with the most precise instrument yet developed for determining the size and shape of the earth, and for making extremely precise measurements of the distances between land masses.

A joint services effort (the name ANNA is derived from Army, Navy, NASA and Air Force), the satellite carries AFCRL high intensity strobe lights, an Army radio transponder, and a Navy radio doppler transmitter. AFCRL is also responsible for the complex mathematical studies necessary for the calculation of various features of the earth.

ANNA's brilliant lights -- comparable to a second magnitude star -- will be photographed against a background of stars by stellar cameras situated at observing sites around the world. The use of a satellite-borne flashing light is a logical extension of AFCRL research in geodetic stellar triangulation.

Earlier AFCRL experiments with this technique in which flares were released at extreme altitudes by rockets called for the use of several stellar cameras which simultaneously photographed the exploding flares against a background of stars. The resultant photographic plates were evaluated to obtain precise directions from the camera sites. By simple triangulation techniques, it was possible to obtain relative positions of the widely separated observing sites with great accuracy.

ANNA's flashing lights, in addition to furnishing geodetic information, will also provide a basis for the study of imprecisely understood perturbations in the orbits of satellites.

Energy for ANNA's powerful strobe lights is provided by solar cells. Capacitors are charged to provide the large bursts of energy to flash the lights. The lights are triggered from the ground. They may be triggered individually or in a pre-determined sequence. Each sequence consists of five flashes with 5.6 second intervals between flashes. Each flash is of one millisecond duration. Its power consumption is equal to that of fourteen thousand 100 watt incandescent lamps,

burning for one-thousandth of a second. Flashing at altitudes ranging from 500 to 600 miles, the lights will be visible to stellar cameras at slant range points of more than 1000 miles. The flashing light system consists of two pairs of straight flash tubes mounted diametrically opposite each other on equatorial flanges of the spherical satellite.

The ANNA program is part of a geodetic research program directed by Mr. Owen W. Williams, Chief of the AFCRL Terrestrial Sciences Laboratory. Mr. Armando Mancini of that laboratory is the Project Scientist. Development of the stellar cameras used in observations of satellite ANNA is under the direction of Mr. Paul B. Swenson, also of that laboratory.

AFOSR

POSTDOCTORAL RESEARCH FELLOWSHIPS

A program of postdoctoral research fellowships, supported by the Air Force Office of Scientific Research, has been established to provide a selected list of young investigators of unusual ability and promise an opportunity for advanced training at appropriate educational institutions in the United States and abroad. It is hoped these fellowships will provide the Air Force the benefit of fresh, original thinking in the various branches of the natural and applied sciences of specific interest to the Air Force. This fellowship program is a continuation of the distinguished National Research Fellowships Program which was supported for many years by the Rockefeller Foundation.

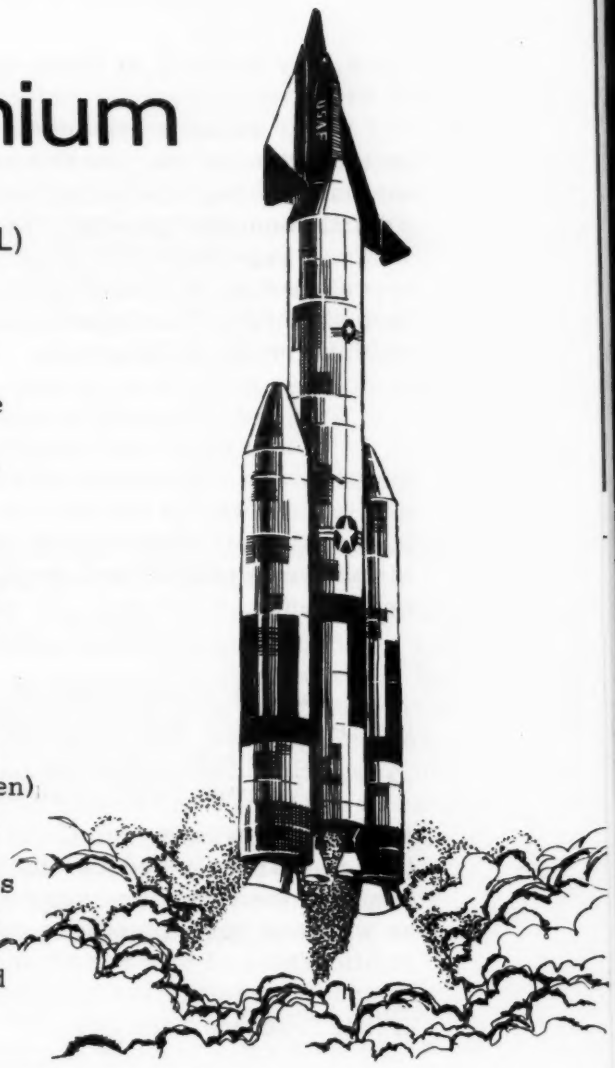
As a prime requisite for selection the candidates must be recent recipients of the doctoral degree. Each applicant must be nominated by a scientist of high professional standing. Fellows will be selected by a Board appointed by the National Academy of Sciences - National Research Council, on the basis of the value of the research the applicant proposes to conduct to the research program of the Air Force.

Each successful Fellow will receive a stipend for the period of his research grant. The basic stipend will be at the rate of $7,500 per annum. An additional allowance of $600 is made for a married Fellow, and an additional increment of $600 a child, to a maximum of $9,300 annually.

Applicants for the academic year 1963-1964 must be filed on or before 14 January 1963. Requests for application blanks or for additional information should be addressed to the Fellowship Office of the NAS-NRC, 2101 Constitution Avenue, Washington 25, D.C.

ductile chromium

ROLLIN E. HOOK and ATTWELL M. ADAIR
Metallurgy and Ceramics Research Laboratory (ARL)



The refractory metals and their alloys are of considerable interest to the U. S. Air Force for use in aerospace vehicles. Attention is drawn to these materials because of their high temperature strength properties. However, brittleness particularly in the Group VI A metals (Cr - Mo - W) poses a serious problem. These metals in the recrystallized condition usually exhibit quite high ductile-brittle transition temperatures (in the neighborhood of 300 - 400°C), although that for Mo has been reduced to sub-zero temperatures by purification. Both Mo and W (tungsten) pose serious oxidation problems in that they form volatile oxides and must be protected by coatings. Chromium offers great promise as an oxidation resistant material; however, until recently its apparently hopeless brittle nature would preclude its usefulness.

The metal chromium is of considerable scientific interest insofar as its utilization for the study of various phenomena is concerned, some of which may be unique and others which may have general applicability to refractory metals.

Of particular interest is the phenomenon of recrystallization embrittlement rheotropic recovery exhibited by Cr and also by Mo and W. Cr of the highest purity available in a usable form with which to conduct mechanical property studies (99.98 weight % Cr) generally exhibits a Ductile - Brittle tensile transition temperature of about 300°C in the recrystallized condition and about - 10°C in the wrought form. Deformation of recrystallized Cr above the transition temperature

promotes ductility at lower temperatures.

The authors hypothesized that the brittleness of Cr. is related to the grain boundaries and probably to the detrimental effect of small amounts of segregated impurities. A program of research was designed and conducted to study the role of grain boundaries on the brittleness of Cr. Experiments were conducted to assess whether the controlling mechanism is predominately one of crack initiation or crack progagation, and whether brittle fracture is initiated predominately by grain boundary rupture or by cleavage.

It was found that single crystals of Cr exhibited excellent tensile ductility at room temperature. Elongations of 40-50% were exhibited and failure was of the ductile chisel point rupture type. This result lead to further experiments in which the dependence of the D-B transition temperature upon grain diameter and specimen diameter was examined.

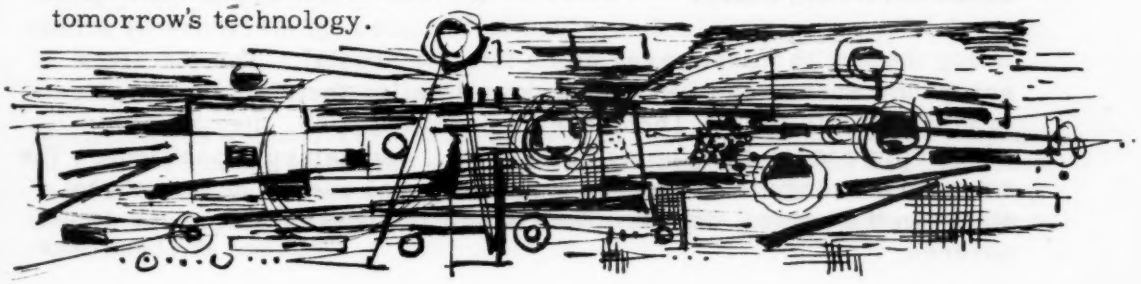
Data obtained using two widely different grain sizes showed that the D-B tensile transition temperatures decreased from 225°C to -80°C as $S = \frac{\text{Specimen Diameter}}{\text{Average Grain Diameter}}$ was decreased from a value of 36 to 4. In other words, for Cr of a given grain size the transition temperature is markedly reduced as the specimen diameter is reduced. Evidence in the literature suggests that this result may be common to Mo as well and perhaps others of the refractory metals. The theoretical implications of this result may be of great significance and are currently under investigation in regard to the plastic flow properties as well as brittle fracture behavior.

Fractographic studies revealed that the fracture nucleus in recrystallized Cr is predominately an intergranular rupture site and that propagation of the gross fracture then occurs almost entirely by transgranular cleavage. Second phase particles of chromium-oxide are found on grain broundary rupture surfaces and are found distributed along grain boundaries by metallographic techniques. Intergranualr oxide particles form in Cr upon annealing at 1300°C and above. These particles appear only in samples rapidly cooled from temperature and not in samples furnace-cooled or in samples rapidly cooled and subsequently annealed below 1300°C. Studies are being conducted to examine this peculiar reversion phenomena in more detail.

Examination of the rheotropic recovery phenomena revealed that Cr prestrained in tension above its transition temperature (125°C) could be subsequently strained at lower temperatures, and pre-yield brittle fracture was not encountered until the temperature was lowered to between - 50°C and -100°C. An experiment involving straining at 0°C, annealing at high temperature, restraining at 0°C, etc. was carried out on a single specimen following an initial prestrain above its transition temperature of 125°C. Re-embrittlement at 0°C did not occur after annealing at 400, 700, and 900°C. After annealing at 1100°C, the specimen was completely brittle on testing at 0°C. It appears that recrystallization is necessary for re-embrittlement to occur following rheotropic recovery.

The results of this research suggest that the important criterion for brittle fracture in Cr is whether or not a microcrack can be nucleated. In recrystallized Cr. fracture initiation occurs at grain boundaries predominately by slip or twin induced intergranular rupture, and brittle fracture then results primarily by transgranular cleavage. The ductile-brittle behavior of Cr. is analogous in many respects to that of Mo. However, the oxide of Mo which segregates at grain boundaries and imparts brittleness, is volatile, and Mo can be rid of its harmful effect through vacuum annealing. This research has shown the presence of oxides in the grain boundaries in Cr and suggests that oxygen may promote grain boundary initiated fracture. However, we await the production of an exceedingly high purity Cr to assess the effect of the impurity or impurities responsible for its brittle behavior.

The experimental results described herein offer a more complete understanding of the ductile-brittle behavior of Cr. They emphasize the importance of grain boundaries, perhaps one of the least understood structural features of metals, on the mechanical response of Cr. Cr offers itself as a vehicle to be used in the study of various metallurgical phenomenon, the understanding of which will lead to the advancement of tomorrow's technology.



vibration patterns in CRYSTALS

Electronic Material Sciences Laboratory (AFCRL)

A previously unseen and unsuspected motion of atoms in a crystal has been reported by Westinghouse Research Laboratories, under research support by AFCRL.

The motion is the shaking, or acoustic vibration, of a few atoms at widely scattered places where defects occur in the orderly structure of a crystal. Until now, theory has predicted that all parts of a crystal must vibrate together or coherently. Crystals of quartz were used in finding the new phenomenon.

The discovery is a basic advance in understanding of crystal structure and behavior. But beyond that, the new information may help to raise the present operating temperatures of lasers and masers, now a limitation on both devices. The new knowledge may explain the peculiar effect of neutron radiation on fused quartz, a widely used electronic material.

The effect was observed by tipping over the magnetic spine of "free" electrons trapped at the crystal defects and watching them return to normal. In doing this, the electron spins were kept in an upside-down position for periods of several hours.

The defects used in the Westinghouse study were produced by irradiation of quartz (silicon dioxide) with neutrons. The defect itself is a single "free" electron trapped on a silicon atom. It has two pairs of silicon atoms as neighbors and is located at a spot where two adjacent oxygen atoms are missing.

Because electrons have charge and spin, they behave as tiny magnets and can be lined up by the magnetic field of a strong external magnet. A superconducting magnet, weighing only about a pound, was used in the experiment. The quartz sample, held inside the hollow coil of the magnet, is immersed in liguid helium at a temperature only 4.2 degrees above absolute zero. This temperature is about 452 degrees below zero Fahrenheit.

Additional enegry is then added to the lined-up electrons by stimulating them with microwaves piped into the crystal. The electrons accept the energy and flip upside down to align their spins opposite to the magnetic field. Then, over a period of time, they lose this added spin energy by flipping back to their former spin positions. The extra spin energy is exchanged for vibrational energy of the nearby atoms in the crystal defect. That is how the local shaking was discovered.

In a perfect quartz crystal, oxygen and silicon atoms are bonded together in a tight, rigid structure. But at a defect, the two missing oxygens leave a dangling silicon atom that can have independent motion, as can other atoms in the neighborhood of the vacancy.

NOTICE TO OUR READERS

Requests for further information should be directed to the individual or laboratory of origin.

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
Attn: CRI
Laurence G. Hanscom Field
Bedford, Massachusetts

AERONAUTICAL RESEARCH LABORATORIES
Attn: ARO
Wright-Patterson Air Force Base, Ohio

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Attn: SRIL
Tempo D Building
4th and Independence Avenue, S.W.
Washington 25, D.C.

For documentary reports on research referred to in articles:

*ARMED SERVICES TECHNICAL INFORMATION AGENCY
Arlington Hall Station
Arlington 12, Virginia

OFFICE OF TECHNICAL SERVICES
U.S. Department of Commerce
Washington 25, D.C.

* Qualified requestors.

RESEARCH REVIEW is published by the Office of Information (RREI), Office of Aerospace Research, USAF, Washington 25, D. C. The frequency of this publication is determined solely on the basis of the availability of significant material to report. The objective is to make a positive contribution to the exchange of information about Air Force sponsored and conducted basic research activities. Individuals or groups associated with basic research may obtain copies by written request to the above address.

GPO 936493